

(19)



Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number:

0 061 241
A1

(12)

EUROPEAN PATENT APPLICATION

(21) Application number: 82300990.7

(51) Int. Cl.³: **C 07 F 15/00**
C 08 G 77/00, C 08 L 83/00

(22) Date of filing: 25.02.82

(30) Priority: 20.03.81 US 245927
20.03.81 US 246104

(43) Date of publication of application:
29.09.82 Bulletin 82/39

(84) Designated Contracting States:
DE FR GB IT NL

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(54) **Platinum-, rhodium-, and iridium-nitrogen complex catalysts.**

(57) A hydrosilation process is disclosed for the reaction between silicon-hydrogen bonds and compounds having aliphatic carbon atoms linked by multiple bonds using as catalysts novel platinum-, rhodium-, or iridium-nitrogen complex compounds of the following classes:

(a) monometallic complexes: (L)PtX₂(Y), (L)RhX(W)₂, and (L)IrX(W)₂

(b) bimetallic complexes: (L)(PtX₂)₂(Y)₂, and (L)[RhX(CO)₂]₂

(c) ionic complexes: (L)PtX₂(Y)(Z), and

(d) reduced forms of monometallic complexes having the formulae:

(1) H[(PNZ)PtX₂(Q)]₂,

(2) [(PNZ)PtX₂(Q)]₂⁻, and

(3) [H(PNZ)PtCl₂(C₂H₄)]₃PtCl₃

wherein

L is a single or fused heterocyclic ligand comprising at least one 5- or 6-member ring, said ligand having 2 to 4 nitrogen ring atoms in the same ring,

Y is an uncharged monodentate ligand that fills only one coordination position of the platinum atom,

W is an uncharged ligand that fills one or two coordination positions of the metal atom, and

X is independently Cl, Br, I, CN, or SCN,

Z is HCl, HBr, or silver trifluoromethane-sulfonate,

Q is an aliphatically unsaturated olefin ligand of 2 to 25 carbon atoms, and PNZ is phenazine.

Preparation of the novel catalysts is described. The cured compositions are useful in the preparation of molded articles.

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PLATINUM-, RHODIUM-, AND
IRIDIUM-NITROGEN COMPLEX CATALYSTS

Technical Field

5 This invention relates to platinum, rhodium, and iridium complex compounds and to their preparation. In another aspect, it relates to a process for hydrosilation using as catalysts platinum, rhodium, or iridium complex compounds. Compositions cured by hydrosilation reactions are useful in molding applications.

10

Background Art

In the presence of catalysts, curable organo-silicone compositions undergo hydrosilation, a reaction involving the addition of a silicon-hydrogen bond across a pair of aliphatic carbon atoms linked by multiple bonds.
15 Reactions of this type are catalyzed by metals, most notably platinum (Pt), rhodium (Rh), iridium (Ir), and palladium (Pd), and compounds thereof. Hydrosilation has found widespread use in the production of silicone materials and organosilanes.

20

Platinum-containing hydrosilation catalysts are known in the art and have been described in numerous patents, such as U.K. Patent Application GB 2,019,426 A, German Patent No. 1,165,028, and U.S. Patent Nos. 2,823,218, 3,814,730, 3,715,334, 3,516,946, 3,474,123,
25 3,419,593, 3,220,972, 3,188,299, 3,178,464, and 3,159,601. These catalysts often suffer from a number of disadvantages: they may be subject to "poisoning" in the presence of certain common materials; they may lack sufficient solubility or dispersibility in organic reaction
30 media; they may be inefficient in promoting a reaction; and in their presence, addition curable organosilicone compositions may lack stability and not exhibit satisfactory pot life.

U.S. Patent No. 3,188,299 discloses nitrogen-
35 containing compounds which are used with a platinum-

containing catalyst to reduce or temporarily inhibit its activity in the presence of an alkenyl polysiloxane and a hydrogen polysiloxane. Although this patent discloses pyrazine as a useful ligand, the proportion of ligand to platinum catalyst used is considerably greater than Applicants' and thereby gives an entirely different product.

Other patents teaching nitrogen- and platinum-containing hydrosilation catalysts are U.K. Patent Application GB 2,019,426 A and German Patent No. 1,165,028. The latter discloses trans-(pyridine)-(ethylene)PtCl₂ as an effective hydrosilation catalyst. U.K. Patent Application GB 2,019,426 A teaches a process for the addition of a silicon-bonded hydrogen atom to an aliphatic multiple bond, which comprises carrying out the addition in the presence of a catalyst which comprises at least one halogen-platinum complex selected from those of the general formulae A₂PtX₂ and C₃H₆PtB₂X₂, in which formulae each A denotes a pyridine ring that is substituted by 1 or 2 alkyl radicals having 1 to 3 carbon atoms, and each X denotes a halogen atom, and each B denotes a 5- or 6-member unsubstituted or substituted heterocyclic ring having 1 or 2 hetero atoms or B₂ denotes two such rings joined together. Neither of these patents discloses a platinum catalyst that has the polynitrogen-containing single or fused ring structure which Applicants have discovered is important in providing increased stability and longer pot life to addition curable organo-silicone compositions.

Compared with platinum, relatively little work has been done on rhodium- and iridium-containing hydrosilation catalysts. Various chloro-rhodium compounds, wherein the valence of rhodium (Rh) is 1, particularly [RhCl(CO)₂]₂ and RhCl(CO)[P(C₆H₅)₃]₂ (A.J. Chalk, J. Organometal. Chem. 21, 207-213 (1970)), [RhCl(C₂H₄)₂]₂ (U.S. Patent No. 3,296,291), and RhCl[P(C₆H₅)₃]₃ (U.S. Patent No. 3,546,266), are disclosed in the literature to

be hydrosilation catalysts. The mono- and bi-metallic pyrazine compounds, (pyrazine)Rh(CO)₂Cl and (pyrazine)Rh₂(CO)₄Cl₂, have been disclosed (A.L. Balch et al., J. Organometal. Chem., 169, 97 (1979)), but no use is specified. R.N. Haszeldine, R.V. Parish and D.J. Perry, J. Chem. Soc. (A), 683 (1969), found that [(C₆H₅)₃P]₂Rh(CO)Cl was active as a hydrosilation catalyst but that the iridium analogue was inactive.

Summary of the Invention

10 Briefly, in one aspect of the invention, there are provided novel platinum-, rhodium-, and iridium-nitrogen complexes useful as hydrosilation catalysts. In another aspect of the invention, there is provided a process for hydrosilation utilizing a platinum-, rhodium-,
15 or iridium-nitrogen complex catalyst, said catalyst being a monometallic, bimetallic, or ionic complex, or reduced forms of the monometallic complex, said process comprising mixing an organosilicone composition, which can be an addition curable composition, with a catalytically
20 effective amount of the platinum-, rhodium-, or iridium-nitrogen complex catalyst, optionally heating the resulting mixture to accelerate its reaction rate, and recovering the resulting organosilane or polysiloxane product.

A further aspect of this invention relates to the
25 method of preparing platinum-, rhodium-, and iridium-nitrogen containing complex hydrosilation catalysts.

"Monometallic" refers to a complex having only one platinum, rhodium, or iridium atom per molecule.

"Bimetallic" refers to a complex having two
30 platinum or rhodium atoms per molecule.

"Ionic" refers to a complex of a monometallic molecule and HCl, HBr, or the silver salt of trifluoromethanesulfonate, which complex dissociates to give positively and negatively charged moieties in certain
35 solvents, e.g., nitromethane and acetonitrile.

"Reduced monometallic forms" refers to forms of monometallic complexes wherein an electron or a hydrogen atom is added to the nitrogen-containing ligand, to be discussed below in detail.

5 "Addition curing" refers to a hydrosilation reaction in which compounds having more than one pair of aliphatic carbon atoms linked by multiple bonds and compounds having more than one silicon-hydrogen bond react together to form a crosslinked polymer.

10 "Pot life" is the time during which the composition containing the curable organosilicone components and the catalyst remains sufficiently fluid to be easily coatable, extrudable, or otherwise processed.

The catalysts of this invention have increased
15 stability, increased dispersibility in reaction media, give lower activation temperatures, are more active catalysts, provide compositions having longer pot life, and are less susceptible to poisoning, as compared to platinum-containing hydrosilation catalysts known in the art.

20 Detailed Description

The hydrosilation catalysts of the present invention are of the following types or classes:

- (a) monometallic complexes: $(L)PtX_2(Y)$, $(L)RhX(W)_2$, and $(L)IrX(W)_2$,
- 25 (b) bimetallic complexes: $(L)(PtX_2)_2(Y)_2$ and $(L)[RhX(CO)_2]_2$,
- (c) ionic complexes, $(L)PtX_2(Y)(Z)$, and
- (d) reduced forms of monometallic complexes having the formulae:
- 30 (1) $H[(PNZ)PtX_2(Q)]_2$,
- (2) $[(PNZ)PtX_2(Q)]_2^-$, and
- (3) $[H(PNZ)PtCl_2(C_2H_4)]_3PtCl_3$

wherein

L is a single or fused heterocyclic ligand comprising
35 at least one 5- or 6-member ring, said ligand having 2 to 4 nitrogen ring atoms in the same ring,
Y is an uncharged monodentate ligand that fills only

one coordination position of the platinum atom, such as olefins, alkyl- or aryl-substituted olefins, phosphines, arsines, sulfides, and amines, the ligands having up to 25 carbon atoms,

5 W is an uncharged ligand that fills one or two coordination positions of the metal atom, such a mono- or di-olefin or an alkyl or aryl substituted mono- or di-olefin, said olefin having up to 25 carbon atoms, and

10 X is independently Cl, Br, I, CN, or SCN,

Z is HCl, HBr, or the silver salt of trifluoromethane-sulfonate,

Q is an aliphatically unsaturated olefin ligand of 2 to 25 carbon atoms, and

15 PNZ is phenazine.

Y, an uncharged monodentate ligand, coordinates to the central platinum atom in the complex and occupies one coordination position. It is an olefin such as ethylene, propylene, butylene, styrene, or substituted
20 derivatives thereof, or it may be a group such as triphenylphosphine, triphenylarsine, CO, or $(C_2H_5)_2S$.

W, an uncharged ligand, coordinates to the central metal atom in the complex and occupies one coordination position when W is CO or a mono-olefin, such
25 as ethylene, propylene, butylene, or styrene, or substituted derivatives thereof; or it may occupy two coordination positions when W is a di-olefin such as 1,5-cyclooctadiene (COD), 1,4-cyclohexadiene (CHD), or bicyclo[2.2.1]heptadiene, or substituted derivatives of the
30 di-olefins.

The single or fused ring heterocyclic ligand, L, which preferably is a cyclic structure containing two nitrogen ring atoms in the same ring, which structure can have one, or two or three fused rings. The nitrogen atoms
35 in the same ring may be in any positions; they need not be para to each other. The two-fused ring cyclic structure may be



where the encircled letter D denotes a 6-member carbocyclic aromatic or heterocyclic aromatic ring fused with the depicted dinitrogen heterocycle. Quinoxaline, is the preferred species. In the three-fused ring systems,



the encircled letters D each denote a 6-member carbocyclic aromatic or heterocyclic aromatic ring fused with the depicted dinitrogen heterocycle. Phenazine in this instance is the preferred species; phenazine oxide is also useful. Other useful ligands, of the single ring type, in addition to pyrazine, are five-membered ring structures imidazole and 1,2,4-triazole. The polynitrogen-containing single or polynuclear fused ring structure is important in providing increased stability and longer pot life to these novel catalysts when compared to prior art hydrosilation catalysts.

General preparative methods of the novel catalysts described above will now be described.

Monometallic catalysts of the type $(L)PtX_2(Q)$, wherein L, X, and Q are as defined above, are prepared by combining a polynitrogen ligand L and $KPtX_3(Q)$ in a 1:1 mole ratio in water or a polar organic solvent, such as methanol or acetonitrile. The latter is preferred.

$KPtX_3(Q)$ is prepared by methods known in the art (see A. Wold and J. Ruff, Eds., "Inorganic Synthesis", 14, 90, published 1973 by McGraw Hill) and the polynitrogen-containing single or fused ring substances (referred to herein as L) are commercially available. The complex salts precipitate from the reaction mixture. These olefin complexes may be subsequently converted to other novel catalytically active compositions by displacement of the olefin. For example, $(L)PtX_2(Y)$ and $(L)(PtX_2)_2(Y)_2$,

wherein L and X are as defined above and Y is a neutral ligand selected from diethyl sulfide, carbon monoxide, triphenylphosphine, triphenylarsine, and styrene, can be prepared by displacement of the olefin. Preferably the
5 olefin has the formula $R_2C=CR_2$, wherein each R is independently H, an alkyl group of up to 20 carbon atoms, or an aryl group having up to 10 ring carbon atoms, with the proviso that not more than two R groups are aryl. Typically, $(L)PtX_2(Q)$ and the ligand Y are combined in a
10 1:1 molar ratio in an aprotic organic solvent such as benzene, chloroform, or acetonitrile and then heated at the reflux temperature. If CO is to be incorporated, it is used in excess because it is a gas. The $(L)(PtX_2)(Y)$ compound is isolated by evaporation of the filtered
15 reaction mixture.

Monometallic catalysts of the type $(L)RhX(W)_2$ and $(L)IrX(W)_2$, wherein L, W, and X are as defined above, are prepared by combining L, the polynitrogen ligand, and the dimer of the type $[MW_2X]_2$ in a 2:1 mole ratio in an organic
20 solvent, such as benzene, toluene, methanol, acetonitrile, methylene chloride, or chloroform. The preferred solvent is methylene chloride. The complex salts are recovered from the reaction mixture. Starting materials $[M(olefin)_2X]_2$, wherein M and X are as defined above, and
25 $[Rh(CO)_2Cl]_2$ are commercially available. Useful polynitrogen-containing single or fused ring substances, L, are available from Aldrich Chemical Co. Preferably the olefin has the structure $R_2C=CR_2$, wherein each R is independently H, an alkyl group of up to 20 carbon atoms, or an aryl
30 group having up to 10, and preferably 6 ring carbon atoms, with the proviso that not more than one R group on each carbon atom is aryl. The preferred olefinic ligand is COD.

Because Y contains more than 1 donor nitrogen atom, additional novel catalytically active bimetallic
35 complexes of the formula $(L)(PtX_2)_2(Y)_2$ can be prepared in which at least two nitrogen atoms in the heterocyclic moiety are linked to platinum atoms. These complexes of

the formula $(L)(PtX_2)_2(Y)_2$ are formed as coproducts with complexes of the formula $(L)PtX_2(Y)$, wherein L, X, and Y are as defined above, in the displacement reactions. They have low solubility in the reaction mixture and are easily isolated by filtration.

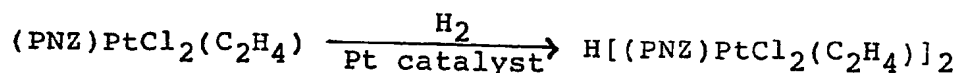
Because L contains more than 1 donor nitrogen atom, additional novel catalytically active bimetallic compounds of the formula $L[RhX(CO)_2]_2$ can be prepared, in which at least two ring nitrogen atoms in the heterocyclic ligand are linked to rhodium atoms. These compounds of the formula $L[RhX(CO)_2]_2$ are formed by combining L and $[Rh(CO)_2X]_2$ in a 1:1 molar ratio, wherein L and X are as defined above. They are removed from the reaction mixture and are easily isolated by filtration.

Ionic complex salts formed from complexes of the formula $(L)PtX_2(Y)$ are prepared by combining the platinum compound and a protic acid (e.g., HBr or HCl) or a salt (e.g., $AgCF_3SO_3$) in a nonpolar organic solvent such as dichloromethane, benzene, or hexane, to yield complexes of the formula $(L)PtX_2(Y)(Z)$ in which L, X, and Y are as defined above and Z is HBr, HCl, or $AgCF_3SO_3$.

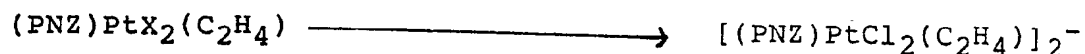
Included also in the novel class of hydrosilation catalysts are the reduced forms of the monometallic complexes, wherein PNZ represents phenazine, and X and Q are as defined above. The reduction of the monometallic complexes of the invention leads to platinum complexes having enhanced reactivity and the reduction can be accomplished by electrolysis or by reaction with hydrogen, alkali metals, or silanes, as will be discussed below. These complexes and radicals have the formulae $H[(PNZ)PtX_2(Q)]_2$, $[(PNZ)PtX_2(Q)]_2^-$, and $[H(PNZ)PtCl_2(C_2H_4)]_3PtCl_3$, wherein PNZ, X, and Q are as defined above. By reduced form is meant addition of an electron or hydrogen atom to yield an oligomerized product of, for example, (phenazine) $PtCl_2$ (ethylene). The dimeric $H[(PNZ)PtCl_2(C_2H_4)]_2$, so produced is useful as a hydrosilation catalyst and it is a more reactive catalyst than

the precursor, (PNZ)PtCl₂(C₂H₄). Specifically, reduction of the monometallic phenazine platinum complexes to form H[(PNZ)PtX₂(Q)]₂ can be accomplished by using hydrogen in the presence of a platinum catalyst such as

5 PtCl₂[(C₂H₅)₂S]₂ or, preferably, platinum black, in an aprotic solvent such as toluene or, preferably, dichloromethane, according to the following chemical equation:



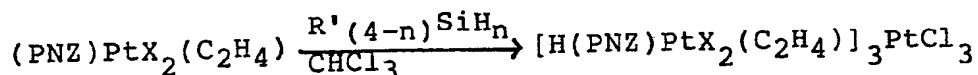
Reduction of (PNZ)PtX₂(Q) complexes is also
10 accomplished by electrolysis in a polar organic solvent such as acetonitrile or dichloromethane and in the presence of a supporting electrolyte, such as tetra-n-butylammonium fluoroborate, until approximately 0.5 Faradays per mole of Pt have been consumed. Alternatively, reduction can be
15 carried out using an alkali metal amalgam or an alkali metal with or without a carrier, such as naphthalene, being present. Solvents used in metal reductions are ethers, such as tetrahydrofuran or 1,2-dimethoxyethane. The molar ratio of alkali metal to platinum complex is 0.5 to 1 with
20 further reduction leading to decomposition. For the (PNZ)PtCl₂(C₂H₄) complex, the three alternative reactions that take place are as follows:



- 25 (1) electrolysis, or
(2) alkali metal
amalgam, or
(3) alkali metal

Reduction of (PNZ)PtX₂(C₂H₄) to form the catalyst
[H(phenazine)PtCl₂(C₂H₄)]₃PtCl₃ occurs in chloroform.
30 Suitable reductants include trialkyl-, triaryl- or trialkoxysilanes of the type R' (4-n)SiH_n, wherein n is an integer of 1 to 3, R' is an alkyl group having up to 10 carbon atoms, an alkoxy group having up to 4 carbon atoms, phenyl, or diphenyl. Preferred silicon-containing

reductants are $(C_6H_5)_3SiH$ or $(CH_3O)_3SiH$. The reactions that take place may be written as follows:



5 The proportion of complex present in the organo-silicone compositions of the present invention can vary widely, but generally an amount sufficient to provide 1 to 1000 ppm by weight of platinum, rhodium, or iridium to the weight of the coreactants is useful.

10 Addition cure or hydrosilation reactions produce organosilanes and polysiloxanes. The catalyst-containing organosilicone compositions of the present invention are formable materials ranging from thin pastes to stiff plastic, dough-like substances. They may be shaped, as by molding or extruding, after which the silicone article is
15 converted to a rubbery state by curing. The rubbery fabricated articles formed thereby may be, for example, O-rings, gaskets, and tubing.

Objects and advantages of this invention are further illustrated by the following examples, but the
20 particular materials and amounts thereof recited in these examples, as well as other conditions and details, should not be construed to unduly limit this invention.

EXAMPLE 1

Synthesis of the Complex Platinum-Nitrogen Catalysts .

25 A. (Phenazine) $PtCl_2(C_2H_4)$

Phenazine, 3.3 mmole (0.60 g), in 20 ml hot acetonitrile was added to a solution of 3.3 mmole (1.28 g) $KPtCl_3(C_2H_4)$ in 20 ml of the same solvent. The resulting turbid solution was allowed to stand at room temperature
30 for 24 hours. The solids which separated were collected on a filter and recrystallized by slow evaporation of dichloromethane-ethanol solution to give 0.58 g of product as yellow needles. The original mother liquor was evaporated and the residue similarly recrystallized to give

0.32 g of additional product. The total yield was 0.90 g (59%). Spectroscopic analysis confirmed the product as (phenazine)PtCl₂(C₂H₄). The infrared spectrum exhibited a single Pt-Cl stretching band indicative of trans stereo-
 5 chemistry. The analogous pyrazine and quinoxaline platinum-nitrogen complexes were prepared in a similar manner. Also, (phenazine)PtCl₂(C₃H₆) can be prepared using KPtCl₃(C₃H₆).

10 Using the same general method described above, the following complex catalysts were synthesized and their compositions were confirmed by elemental analysis.

TABLE I
Complex

- | | |
|----|---|
| 15 | 1. (pyrazine)PtCl ₂ (C ₂ H ₄) |
| | 2. (quinoxaline)PtCl ₂ (C ₂ H ₄) |
| | 3. (phenazine)PtCl ₂ P(C ₆ H ₅) ₃ |
| | 4. (phenazine)PtCl ₂ (C ₆ H ₅ CH=CH ₂) |
| | 5. (phenazine-N-oxide)PtCl ₂ (C ₂ H ₄) |
| | 6. (phenazine)[PtCl ₂ (styrene)] ₂ |
| 20 | 7. [2,3,5,6-(CH ₃) ₄ pyrazine]PtCl ₂ (C ₂ H ₄) |
| | 8. (phenazine)PtCl ₂ (C ₂ H ₄)·AgCF ₃ SO ₃ |
| | 9. (phenazine)PtCl ₂ [S(C ₂ H ₅) ₂] |
| | 10. (phenazine)PtCl ₂ (C ₂ H ₄)·HCl |
| | 11. (phenazine)PtCl ₂ As(C ₆ H ₅) ₃ |
| 25 | 12. (phenazine)[PtCl ₂ As(C ₆ H ₅) ₃] ₂ |
| | 13. (phenazine)[PtCl ₂ P(C ₆ H ₅) ₃] ₂ |

B. (Phenazine)PtCl₂(C₂H₄)·CF₃SO₃Ag

(Phenazine)PtCl₂(C₂H₄), 1.0 mmole (0.47 g), in 30 ml hot benzene was added to a solution of 1.0 mmole
 30 (0.246 g) silver trifluoromethanesulfonate in 6 ml of the same solvent. After 15 minutes, the yellow product was collected on a filter, washed with benzene and vacuum dried. The yield was 0.57 g. Conductivity studies and spectroscopic analysis indicated the formation of
 35 (phenazine)PtCl₂(C₂H₄)·CF₃SO₃Ag.

C. (Phenazine) $\text{PtCl}_2(\text{C}_2\text{H}_4) \cdot \text{HCl}$

A stream of anhydrous hydrogen chloride was passed through a solution of 0.5 g (phenazine) $\text{PtCl}_2(\text{C}_2\text{H}_4)$ in dichloromethane. The reaction mixture was filtered and the filtrate saved. The solids were recrystallized by slow evaporation of a dichloromethane-ethanol solution to give 0.1 g of product. The above filtrate was treated with heptane and concentrated to give solids which were similarly recrystallized to give 0.15 g additional product. Spectroscopic and elemental analyses were the same for the two crops and confirmed the identity of the compound to be compound 10 in TABLE I.

D. (Heterocyclic amine) $\text{PtCl}_2(\text{CO})$ complexes

Approximately 0.05 g quantities of (amine) $\text{PtCl}_2(\text{C}_2\text{H}_4)$, where the amines are listed below in TABLE II, were placed in vials which were sealed with rubber septa. The vials were thoroughly flushed with nitrogen, then about 1 ml deoxygenated dichloromethane was introduced via syringe. Carbon monoxide was slowly passed through the solutions to effect olefin displacement and formation of the carbonyl complex; this was usually accompanied by a decrease in the intensity of the yellow color. Samples were withdrawn by syringe and spectroscopic analysis showed the presence of the corresponding (heterocyclic amine) $\text{PtCl}_2(\text{CO})$; e.g., where pyrazine was used, the resulting complex was (pyrazine) $\text{PtCl}_2(\text{CO})$.

TABLE II

| | |
|----|-----------------------------|
| | pyrazine |
| | quinoxaline |
| 30 | phenazine |
| | phenazine-N-oxide |
| | 2,6-dimethylpyrazine |
| | 2,3,5,6-tetramethylpyrazine |

E. (Phenazine) $\text{PtCl}_2\text{P}(\text{C}_6\text{H}_5)_3$ and
(phenazine) $[\text{PtCl}_2\text{P}(\text{C}_6\text{H}_5)_3]_2$

Triphenylphosphine (0.5 mmole, 0.13 g) and 0.24 g
(0.5 mmole) (phenazine) $\text{PtCl}_2(\text{C}_2\text{H}_4)$ in 10 ml acetonitrile
5 were refluxed and stirred overnight. The bimetallic
catalyst (phenazine) $[\text{PtCl}_2\text{P}(\text{C}_6\text{H}_5)_3]_2$ precipitated from the
hot reaction mixture and was isolated by filtration. The
yield was 0.1 g. The monometallic catalyst
(PNZ) $\text{PtCl}_2\text{P}(\text{C}_6\text{H}_5)_3$ remained dissolved in the filtrate which
10 was concentrated and cooled to give, upon recrystallization
from acetonitrile, 0.18 g of (PNZ) $\text{PtCl}_2\text{P}(\text{C}_6\text{H}_5)_3$ as yellow
plates. Spectroscopic analysis confirmed the identity of
the products.

The styrene and triphenylarsine analogues were
15 prepared in a similar manner. Spectroscopic analysis (see
compounds 4, 6, 11, and 12 of TABLE I above) confirmed the
identity of these products.

F. (Imidazole) $\text{PtCl}_2(\text{C}_2\text{H}_4)$ and
(1,2,4-triazole) $\text{PtCl}_2(\text{C}_2\text{H}_4)$

20 To a solution of 0.37 g (1 mmole) $\text{KPtCl}_3(\text{C}_2\text{H}_4)$
in 15 ml water was added with stirring 0.068 g (1 mmole)
imidazole, dissolved in 3 ml water. The desired
(imidazole) $\text{PtCl}_2(\text{C}_2\text{H}_4)$ separated as a yellow micro-
crystalline solid and was collected on a filter, washed
25 with water and vacuum dried. The yield was 0.26 g, m.p.
119-120°. Elemental analysis confirmed the product to be
(imidazole) $\text{PtCl}_2(\text{C}_2\text{H}_4)$. (Imidazole) $\text{PtCl}_2(\text{C}_3\text{H}_6)$ can be
prepared from $\text{KPtCl}_3(\text{C}_3\text{H}_6)$ using this method.

A similar synthesis of (1,2,4-triazole) $\text{PtCl}_2(\text{C}_2\text{H}_4)$
30 using 1,2,4-triazole was carried out. The yield was 0.18 g
(50%). This compound did not melt and underwent only
slight darkening on heating to 320°C. Elemental analysis
confirmed the product to be (1,2,4-triazole) $\text{PtCl}_2(\text{C}_2\text{H}_4)$.

G. (Phenazine)RhCl(C₈H₁₂)

To 1.25 g (2.5 mmole) [RhCl(COD)]₂ in 30 ml. acetonitrile was added 0.90 g (5.0 mmole) phenazine in a minimum amount of warm acetonitrile. Needle crystals began to separate from the orange solution and, after 0.5 hr., they were collected on a filter, washed with fresh solvent and vacuum dried. The yield was 1.6 g (75%). Spectroscopic and elemental analyses confirmed the crystalline material to be (phenazine)RhCl(C₈H₁₂).

Using the method just described, (phenazine)RhBr-(C₈H₁₂) and (phenazine-N-oxide)RhCl(C₈H₁₂) were prepared using [RhBr(COD)]₂ or phenazine-N-oxide as starting materials. Spectroscopic and elemental analyses confirmed the identity of these compounds.

H. (Quinoxaline)RhCl(C₈H₁₂)

Quinoxaline, 1.66 mmole in 2 ml. acetonitrile, was added to a solution of 0.41 g. (0.83 mmole) [RhCl(COD)]₂ in 20 ml. of the same solvent. The mixture was evaporated to 2 ml. with a nitrogen jet. The remaining solution was heated to boiling and filtered. On cooling, the product separated as yellow nodules. It was filtered and vacuum dried; yield 0.2 g. (32%). Spectroscopic and elemental analyses confirmed the identity of the product to be (Quinoxaline)RhCl(C₈H₁₂).

I. (Phenazine)IrCl(C₈H₁₂)

Cyclooctadiene iridium(I) chloride dimer was prepared from hydrated IrCl₃ by the method disclosed in "Organometallic Synthesis", 1, R. Bruce King, Academic Press, N.Y., 1965, p. 132. A 0.95 g. sample of this crude dimer was dissolved in 25 ml. methylene chloride and the solution filtered. Phenazine, 0.51 g. (2.8 mmole) was added. The resulting orange solution was evaporated to a small volume under reduced pressure and diluted with ethanol. On cooling to -20°C, 0.8 g. of red-brown solid separated. This was recrystallized from hot acetonitrile

to give 0.20 g. of the iridium complex as dark brown needles. Spectroscopic and elemental analyses confirmed the identity of the product to be (phenazine)IrCl(C₈H₁₂).

J. (Phenazine)RhCl(CO)₂

5 A solution of 0.36 g. (2 mmole) phenazine in 10 ml. benzene was added dropwise to 0.4 g. (1 mmole) resublimed [RhCl(CO)₂]₂ in 35 ml. benzene. The resulting orange solution was evaporated to 3 ml. under reduced pressure and diluted with hexane to give 0.60 g. (80%) of
10 product as yellow needles. Spectroscopic and elemental analyses confirmed the identity of the product to be (phenazine)RhCl(CO)₂. The infrared spectrum contained two Rh-carbonyl stretching bands indicative of cis stereochemistry.

15 Using the method just described, (phenazine-N-oxide)RhCl(CO)₂ was prepared utilizing phenazine-N-oxide in place of phenazine and its identity was confirmed by spectroscopic and elemental analyses.

K. (Phenazine)[RhCl(CO)₂]₂

20 This bimetallic compound was prepared using the method of EXAMPLE J and half the amount of phenazine. The yield of orange, crystalline material was 0.45 g. (79%). Spectroscopic and elemental analyses confirmed the identity of the product to be (phenazine)[RhCl(CO)₂]₂.

L. (Imidazole)RhCl(CO)₂

25 A solution of 0.19 g (0.5 mmole) [Rh(CO)₂Cl]₂ in 10 ml chloroform was added to 0.069 g (1 mmole) imidazole in 3 ml of the same solvent. The yellow solution was
30 diluted to the cloud point with heptane and then concentrated without heating on the rotary evaporator. Yellow crystals of (imidazole)RhCl(CO)₂ separated and were collected on a filter and vacuum dried. The yield was 0.20 g, m.p. 77-80°C. Elemental analyses confirmed the identity

of the product to be (imidazole)RhCl(CO)₂. The infrared spectrum contained two Rh-carbonyl stretching bands indicative of cis stereochemistry.

5 Orange crystals of (1,2,4-triazole)RhCl(CO)₂ (m.p. decomposes) were prepared by a similar method using 1,3,4-triazine in place of imidazole. Spectroscopic and elemental analyses identified this product.

M. (Phenazine)IrCl(CO)₂

10 A mixture of 0.31 g (1 mmole) of polymeric [IrCl(CO)₃], and 0.18 g (1 mmole) of phenazine in 25 ml acetonitrile was stirred under reflux for 16 hr, then filtered. The filtrate was diluted to the cloud point with hexane and then cooled to -20°. The yellow crystals which separated were collected on a filter. Unreacted phenazine
15 was removed from this crude product by heating the material in a sublimar (80°C, 3 x 10⁻³ mm.) fitted with a dry ice cooled probe. The yield of pure, yellow crystalline product was 0.075 g, m.p. 195°C. Spectroscopic and
20 elemental analyses indicated the product to be (phenazine)IrCl(CO)₂. The infrared spectrum contained two Ir-carbonyl stretching bands indicative of cis stereochemistry.

EXAMPLE 2

Reduction of Complex Platinum-Nitrogen Catalysts

25 A. Reduction of (phenazine)PtCl₂(C₂H₄) with hydrogen

A solution of 0.40 g of (phenazine)PtCl₂(C₂H₄) in 20 ml dichloromethane was prepared under nitrogen. Platinum black (5 mg) was added and a slow stream of
30 hydrogen passed over the stirred reaction mixture for 3.5 hours. Filtration afforded 0.26 g of product as a dark green solid which was washed with dichloromethane, dried by pumping and stored under vacuum. Spectroscopic and

elemental analyses confirmed the identity of the product to be $\text{H}[(\text{phenazine})\text{PtCl}_2(\text{C}_2\text{H}_4)]_2$.

B. Electrochemical reduction of
(phenazine) $\text{PtCl}_2(\text{C}_2\text{H}_4)$

5 Electrochemical measurements in this example were made using the conventional three electrode technique. A water jacketed cell maintained at 4°C held the sample which was dissolved in 0.1M tetrabutylammonium fluoroborate in dichloromethane. Nitrogen presaturated
10 with solvent was used to deoxygenate the solutions.

Reduction of (phenazine) $\text{PtCl}_2(\text{C}_2\text{H}_4)$ was carried out at -0.9 V (relative to a saturated calomel reference electrode) until the current had declined to 4% of the initial value at which point 0.49 Faradays per mole of
15 platinum had been passed. Aliquots of the deep green solution were transferred with a syringe to nitrogen filled EPR tubes or to a rectangular cuvette for electronic spectroscopy. Spectroscopic analysis confirmed the identity of $[(\text{phenazine})\text{PtCl}_2(\text{C}_2\text{H}_4)]_2^-$. The cation
20 was tetrabutylammonium ion.

C. Reduction of (phenazine) $\text{PtCl}_2(\text{C}_2\text{H}_4)$ with sodium metal

Five milliliters of degassed acetonitrile (dried with 5A molecular sieves) were condensed onto 0.047 g
25 (phenazine) $\text{PtCl}_2(\text{C}_2\text{H}_4)$ and 0.26 g of 0.44% sodium amalgam. After shaking for about five minutes, the green solution was filtered through a coarse frit into an EPR tube. A sample for electronic spectroscopy was similarly prepared. The epr and visible spectrum confirmed the identity of
30 $[(\text{PNZ})\text{PtCl}_2(\text{C}_2\text{H}_4)]_2^-$. The product matched that of the material prepared electrochemically, in EXAMPLE 2B, except that the cation was sodium ion.

Similar reductions were carried out using sodium amalgam in dimethoxyethane or sodium naphthalide in tetra-
35 hydrofuran with similar results. When these reactions

were carried out for a prolonged period, the green color was replaced by the red phenazine anion radical and eventually a platinum mirror formed on the walls of the reaction vessel.

5

EXAMPLE 3

Reaction of (phenazine) $\text{PtCl}_2(\text{C}_2\text{H}_4)$ with triphenylsilane

A mixture of 0.47 g of the platinum compound, 0.27 g triphenylsilane, and 25 ml. chloroform (freshly distilled from CaSO_4) was stirred under nitrogen for 15 min. then allowed to stand for 3 hr. The fine black microcrystals, 0.23 g, were collected on a frit, washed with fresh solvent, vacuum dried and stored under nitrogen. Spectroscopic and elemental analyses confirmed the identity of $[\text{H}(\text{PNZ})\text{PtCl}_2(\text{C}_2\text{H}_4)]_3\text{PtCl}_3$.

15

Other silanes found capable of reducing (PNZ) $\text{PtCl}_2(\text{C}_2\text{H}_4)$ were 1,1,2-trimethyldisilane, 1,1,1-trimethyldisilane, diethoxysilane, phenylsilane, diethylsilane, octylsilane, pentamethyldisiloxane, and diphenylsilane.

20

EXAMPLE 4

Hydrosilation Reactions

A. Hydrosilation of 1-methylcyclohexene using a Pt-N complex catalyst

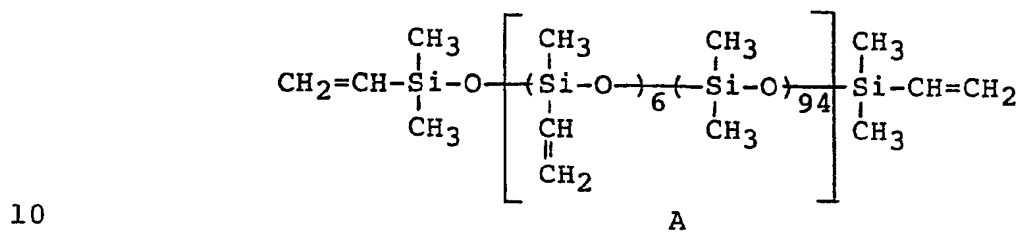
25

A mixture of 20 ml trichlorosilane, 25 ml chloroform, 8.1 g 1-methylcyclohexene and 0.055 g (phenazine) $\text{PtCl}_2(\text{C}_2\text{H}_4)$ was refluxed and stirred under nitrogen for 6 days. Distillation of the reaction mixture afforded 2.2 g of trichlorosilylmethylcyclohexane $\text{C}_6\text{H}_{11}\text{CH}_2\text{SiCl}_3$ which was characterized by its mass and NMR spectra.

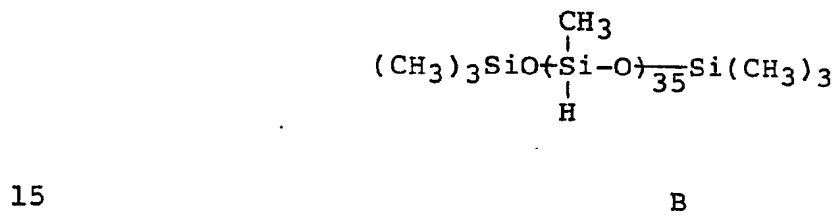
30

B. Addition curing by hydrosilation using
platinum-nitrogen complex catalysts

At the concentration shown below in TABLE III,
several platinum catalysts were dispersed in an oligomer
5 fluid of average composition A.



A crosslinking agent of oligomer composition B



was added at 5 wt% of the total composition. The
temperature at which gelation (formation of a rigid
polymer) occurred in less than 5 sec. (i.e., the
activation temperature) was determined on a "Kofler
20 Heizbank" hot bar (Reichert, Austria). Hydrosilation
caused crosslinking of the oligomers with a drastic
increase in viscosity; a very active catalyst yielded a
rigid polymer in all cases. The results are shown below
in TABLE III and indicate that (phenazine)PtCl₂(C₂H₄)
25 provides lower activation temperatures and longer gel
times at ambient temperatures than the controls, complex
catalysts (pyridine)PtCl₂(C₂H₄) and PtCl₂[S(C₂H₅)₂]₂. This
is particularly apparent in the cases where the catalysts
are used at low concentrations. Low concentrations of
30 platinum are desirable due to the high cost of this
chemical element.

TABLE III

| Catalyst | Pt conc., ppm* | Activation temp., **°C | Gel time, *** hours at 27°C |
|--|-------------------|---------------------------|--------------------------------|
| 5 (phenazine)PtCl ₂ (C ₂ H ₄) | 100 | 100 | 0.5 |
| | 50 | 110 | 3 |
| | 10 | 120 | 10 |
| (pyridine)PtCl ₂ (C ₂ H ₄) (control) | 100 | 110 | 0.2 |
| | 50 | 130 | 3 |
| | 10 | 150 | 4 |
| 10 PtCl ₂ [S(C ₂ H ₅) ₂] ₂ (control) | 100 | 110 | 0.1 |
| | 50 | 120 | 0.5 |
| | 10 | 130 | 2 |

* relative to weight of A

** temperature at which gelation occurs in less than 5 sec

15 *** time required to form a rigid polymer at 27°C using ASTM method
D-2471-71, reapproved 1979

The above data also show that (phenazine)PtCl₂(C₂H₄) oligomer mixture was more stable in that it had a pot life 2-1/2 times longer than that of the controls but had an activation temperature 30°C lower than (pyridine)PtCl₂(C₂H₄) at 10 ppm Pt concentration. Lower activation temperature is particularly advantageous when it is desired to carry out the curing process on a thermally labile substrate.

25 Using the same general method just described, the following complexes were found to exhibit similar catalytic activity in the curing of oligomers A and B:

TABLE IV

Complex

| | |
|----|---|
| | (phenazine)PtCl ₂ (C ₂ H ₄)·AgSO ₃ CF ₃ |
| | (phenazine)PtCl ₂ (styrene) |
| | (phenazine)PtCl ₂ (C ₂ H ₄)·HCl |
| 5 | (phenazine)PtCl ₂ S(C ₂ H ₅) ₂ |
| | (quinoxaline)PtCl ₂ (C ₂ H ₄) |
| | (pyrazine)PtCl ₂ (C ₂ H ₄) |
| | (phenazine)PtCl ₂ P(C ₆ H ₅) ₃ |
| | (phenazine oxide)PtCl ₂ (C ₂ H ₄) |
| 10 | H[(phenazine)PtCl ₂ (C ₂ H ₄)] ₂ |
| | [(C ₄ H ₉) ₄ N][(phenazine)PtCl ₂ (C ₂ H ₄)] ₂ |
| | [H(phenazine)PtCl ₂ (C ₂ H ₄)] ₃ PtCl ₃ |

H[(phenazine)PtCl₂(C₂H₄)]₂ and H₃[(phenazine)PtCl₃(C₂H₄)]₃, prepared in EXAMPLE 3, were also found to have activity (at 100 ppm Pt) as hydrosilation catalysts. A concentration of 100 ppm Pt of the complex to be tested was added to oligomers A and B and the mixture stirred. Hydrosilation caused crosslinking of the oligomers with a drastic increase in viscosity.

20 C. Shaped article

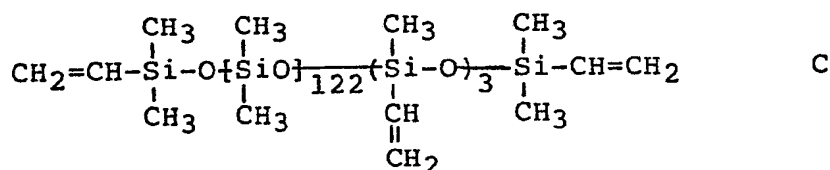
The polymer produced in B. above, using (phenazine)PtCl₂(ethylene) as the catalyst, was poured into a heated mold (110°C) shaped as a gasket. A solid, rubbery gasket was extracted from the mold after 15 min.

25 D. Use of rhodium-nitrogen complexes as catalysts in hydrosilation reactions

Utility of several rhodium complexes as hydrosilation catalysts was evaluated using two vinyl functional siloxane polymers, C and D, described below in TABLES V and VI. A solution was prepared by adding the rhodium compound in 2 ml. dichloromethane to the vinyl functional siloxane and evaporating the dichloromethane. Typical rhodium concentrations were 25-50 ppm metal by weight. DC-1107, (polyhydrosiloxane crosslinker,

(CH₃)₃Si[CH₃Si(H)O]₃₅Si(CH₃)₃, Dow Corning Co.), 0.5 ml., was added to 10 ml. of the catalyst-containing vinylsiloxane, and the gel times (i.e., the time it takes for crosslinking to a rubbery state to occur as determined by ASTM method D-2471-71, reapproved 1979) were measured. The more efficient the catalyst, the more rapid is the crosslinking hydrosilation reaction and, therefore, the shorter is the gel time. For comparison, certain runs were made with controls using compounds known in the prior art, i.e., [(COD)RhCl]₂ and (pyridine)RhCl(COD).

TABLE V



15

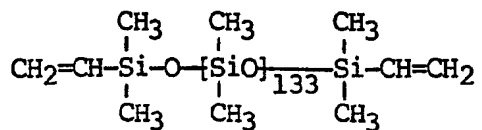
| Run | Catalyst (used with polymer C and DC-1107) | Rh, ppm | Gel time, room temp., min. | Gel time, 90°C, sec. | Temp. for gel time of 5 sec, °C or less |
|-----|---|------------|----------------------------------|-------------------------|---|
| 1. | (phenazine)RhBr(COD) | 25 | >250 | 30 | 120 |
| 2. | (phenazine)RhCl(CO) ₂ | 25 | 120 | 13 | 105 |
| 3. | [(COD)RhCl] ₂ * | 50 | 51 | 17 | 110 |
| 4. | (pyridine)RhCl(COD)* | 25 | 130 | 23 | 115 |

* control

Run 2 had a room temperature gel time comparable to other compositions tested, but its gel time at 90°C was very rapid, indicating it was an effective catalyst at elevated temperatures.

Run 1 had an unusually long gel time at room temperature, this indicating that (phenazine)RhBr(COD) was useful for operations requiring a long pot life. (Phenazine)RhBr(COD) was an effective catalyst at 120°C.

TABLE VI



D

| Run | Catalyst (used with polymer B and DC-1107) | Rh, ppm | Gel time, | | Temp. for gel time of 5 sec, °C or less |
|-----|--|------------|---------------------|-------------------------|---|
| | | | room temp., min. | Gel time, 90°C, sec. | |
| 5 | 5. (phenazine)RhCl(COD) | 25 | 83 | 12 | 105 |
| | 6. (pyridine)RhCl(COD)* | 25 | 80 | 13 | 110 |
| 10 | 7. (phenazine)RhCl(CO) ₂ | 25 | 160 | 10 | 105 |
| | 8. [(COD)RhCl] ₂ * | 50 | 30 | 10 | 100 |

* control

Run 7 was very stable at room temperature yet could be activated at a relatively low temperature of 105°C.

15 The composition of Run 7 was poured into a heated (110°C) mold which was shaped as a gasket. A solid rubbery gasket was extracted from the mold after 15 min indicating that the hydrosilation reaction produced a useful product.

20 E. Use of (pyrazine)[RhCl(CO)₂]₂ as catalyst in hydrosilation reactions.

A mixture was prepared by adding the rhodium complex compound (pyrazine)[RhCl(CO)₂]₂, prepared by the method disclosed in the reference to this complex under the section entitled Background Art above, and 2 ml. dichloromethane to the vinyl functional siloxane represented by polymer C, described above, and evaporating the dichloromethane. The rhodium concentration was 50 ppm metal by weight. DC-1107, (polyhydrosiloxane crosslinker, (CH₃)₃Si[CH₃Si(H)O]₃₅Si(CH₃)₃, Dow Corning Co.), 0.5 ml., was added to 10 ml. of the catalyst-containing vinylsiloxane. The composition was poured into a heated (110°C)

mold which was shaped as a gasket. A solid rubbery gasket was extracted from the mold after 15 min indicating that the hydrosilation reaction produced a useful product.

5 Various modifications and alterations of this invention will become apparent to those skilled in the art without departing from the scope and spirit of this invention, and it should be understood that this invention is not to be unduly limited to the illustrative embodiments set forth herein.

CLAIMS:

1. Platinum-, rhodium-, and iridium- nitrogen complex compounds selected from classes of complexes having the general formulae:

- 5 (a) monometallic complexes: $(L)PtX_2(Y)$, $(L)RhX(W)_2$, and $(L)IrX(W)_2$
- (b) bimetallic complexes: $(L)(PtX_2)_2(Y)_2$ and $(L)[RhX(CO)_2]_2$,
- (c) ionic complexes: $(L)PtX_2(Y)(Z)$, and
- 10 (d) reduced forms of monometallic complexes having the formulae:
 - (1) $H[(PNZ)PtX_2(Q)]_2$,
 - (2) $[(PNZ)PtX_2(Q)]_2^-$, and
 - (3) $[H(PNZ)PtCl_2(C_2H_4)]_3PtCl_3$

15 wherein

L is a single or fused heterocyclic ligand comprising at least one 5- or 6-member ring, said ligand having 2 to 4 nitrogen ring atoms in the same ring,

20 Y is an uncharged monodentate ligand that fills only one coordination position of the platinum atom,

W is an uncharged ligand that fills one or two coordination positions of the metal atom,

25 X is independently Cl, Br, I, CN, or SCN,

Z is HC, HBr, or silver trifluoromethanesulfonate,

Q is an aliphatically unsaturated olefin ligand of 2 to 25 carbon atoms, and

30 PNZ is phenazine.

2. The complex compounds according to Claim 1 selected from the group consisting of

(phenazine) $PtCl_2(C_2H_4)$, (imidazole) $PtCl_2(C_2H_4)$,

(phenazine) $PtCl_2(C_3H_6)$, (imidazole) $PtCl_2(C_3H_6)$,

35 (pyrazine) $PtCl_2(C_2H_4)$, [2,3,5,6-(CH₃)₄pyrazine] $PtCl_2(C_2H_4)$,

(phenazine)RhCl(CO)₂, (phenazine)RhCl(C₈H₁₂),
(phenazine)[RhCl(CO)₂]₂, (imidazole)RhCl(CO)₂,
(quinoxaline)RhCl(C₈H₁₂), (phenazine)IrCl(C₈H₁₂),
(phenazine)IrCl(CO)₂, and (phenazine-N-oxide)RhCl(CO)₂.

5 3. A process for hydrosilation characterized by
the steps of:

 causing a reaction to occur between at least one
silicon-hydrogen bond and a compound having at least one
pair of aliphatic carbon atoms linked by multiple bonds in
10 the presence of a catalytically effective amount of a
platinum-, rhodium-, or iridium-nitrogen complex catalyst
according to any preceding Claim, optionally heating the
resulting mixture, and recovering the resulting product.

 4. The process according to any preceding Claim
15 wherein:

Y represents an olefin ligand having 2 to 25 carbon atoms,
triphenylphosphine, triphenylarsine, CO, or (C₂H₅)₂S,
W is a mono- or di-olefin or an alkyl- or aryl-substituted
mono- or di-olefin having up to 25 carbon atoms, or CO,
20 and
L is cyclic dinitrogen compound, a quinoxaline compound, or
a phenazine compound.

 5. A process for hydrosilation characterized by
the steps of mixing an addition curable organosilicone
25 composition with a catalytically effective amount of a
platinum-, rhodium-, or iridium-nitrogen complex catalyst
according to any preceding Claim, optionally heating the
resulting mixture, and recovering the resulting product.

 6. An addition curable composition of matter
30 comprising:

a. an organosilicone compound having more than one
silicon-hydrogen bond,

- b. an organic compound having more than one pair of aliphatic carbon atoms linked by multiple bonds, and
- 5 c. a catalytic amount of at least one complex compound selected from the complex compounds according to any preceding Claim.

7. The composition according to any preceding Claim wherein said organic compound is a polysiloxane having more than one pair of aliphatic carbon atoms linked
10 by multiple bonds.

8. An addition cured composition of matter comprising the reaction product of:

- a. an organosilicone compound having more than one silicon-hydrogen bond,
- 15 b. an organic compound having more than one pair of aliphatic carbon atoms linked by multiple bonds, and
- c. a catalytic amount of at least one complex compound according to any preceding Claim.

20 9. The addition cured composition according to any preceding Claim wherein said organic compound is a polysiloxane having more than one pair of aliphatic carbon atoms linked by multiple bonds.



European Patent
Office

EUROPEAN SEARCH REPORT

0061241

Application number

EP 82 30 0990

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| Place of search THE HAGUE | | Date of completion of the search 27-04-1982 | Examiner SUTER M. |
| <p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p> | | | |



| DOCUMENTS CONSIDERED TO BE RELEVANT | | | Page 2 |
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